THE SINGLE-PARTICLE AND COLLECTIVE FEATURES IN THE NUCLEI JUST ABOVE ^{132}Sn*

H. Mach[a,b], L.M. Fraile[c], O. Arndt[d], A. Blazhev[e], N. Boelaert[e,f] M.J.G. Borge[g], R. Boutami[g], H. Bradley[b,h], N. Braun[e] B.A. Brown[i], P.A. Butler[j], A. Covello[k], Z. Dlouhy[l] C. Fransen[e], H.O.U. Fynbo[m], A. Gargano[k], Ch. Hinke[n] P. Hoff[o], A. Joinet[c,p], A. Jokinen[q], J. Jolie[e], U. Köster[c,r] A. Korgul[s], K.-L. Kratz[t,u], T. Kröll[n], W. Kurcewicz[s], J. Nyberg[b] E.-M. Reillo[g], E. Ruchowska[v], W. Schwerdtfeger[w] G.S. Simpson[x], M. Stanoiu[y], O. Tengblad[g], P.G. Thirolf[w] V. Ugryumov[l], W.B. Walters[z]

[a]Inst. for Structure and Nuclear Astrophysics, University of Notre Dame, USA
[b]Dept. of Nuclear and Particle Physics, Uppsala University, Uppsala, Sweden
[c]ISOLDE, PH Department, CERN, Geneva, Switzerland
[d]Institut für Kernchemie, Universität Mainz, Mainz, Germany
[e]Institut für Kernphysik, University of Cologne, Cologne, Germany
[f]University of Gent, Gent, Belgium
[g]CSIC, Madrid, Spain
[h]Department of Physics, University of Sydney, Sydney, Australia
[i]Dept. of Physics and Astronomy and NSCL, Michigan State University, USA
[j]Department of Physics, University of Liverpool, Liverpool, UK
[k]Dipartimento di Scienze Fisiche, Universita di Napoli Federico II and Istituto Nazionale di Fisica Nucleare, Napoli, Italy
[l]Institute of Nuclear Physics, Rez, Czech Republic
[m]University of Aarhus, Aarhus, Denmark
[n]Technical University Munich, Garching, Germany
[o]Department of Chemistry, University of Oslo, Oslo, Norway
[p]CESR, Toulouse, France
[q]Department of Physics, University of Jyväskylä, Jyväskylä, Finland
[r]Institut Laue Langevin, Grenoble, France
[s]Institute of Experimental Physics, Warsaw University, Poland
[t]Max-Planck-Institut für Chemie, Otto-Hahn-Institute, Mainz, Germany
[u]HGS Virtuelles Institut für Structur der Kerne und Nucleare Astrophysik, (VISTARS) Mainz, Germany
[v]A. Sołtan Institute for Nuclear Studies, ASINS, Świerk, Poland
[w]Ludvig-Maximilians-University, Munich, Germany
[x]LPSC, Grenoble, France
[y]GSI, Darmstadt, Germany
[z]Department of Chemistry, University of Maryland, MD, USA

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The Advanced Time Delayed method has been used to measure the lifetimes of excited states in the exotic nuclei ^{134}Sb, ^{135}Sb and ^{136}Te populated in the beta decay of ^{134}Sn, ^{135}Sn and ^{136}Sn, respectively. High purity Sn beams were extracted at the ISOLDE separator using a novel production technique utilizing the molecular SnS^+ beams to isolate Sn from contaminating other fission products. Among the new results we have identified the $1/2^+$ state in ^{135}Sb and its E2 transition to the lower-lying $5/2^+$ state was found to be surprisingly collective. This measurement represents also one of the first applications of the $LaBr_3$ scintillator to ultra fast timing.

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1. Introduction

There is a considerable interest in the nuclei just above the exotic doubly magic ^{132}Sn that show unusual features. In particular the B(E2) value for the 0^+ to 2^+ excitation in ^{136}Te was found [1] to be very low implying special cancellation effects. On the other hand, its very close neighbor, ^{135}Sb, shows very low excitation energy of the first excited state at only 282 keV, much lower than expected from shell model considerations raising the possibility [2] of a local shift of the proton single particle $d_{5/2}$ and $g_{7/2}$ orbits due to the neutron excess. From the recently measured [3] lifetime of the 282 keV state one obtains very low E2 and a strongly retarded M1 strength for the 282 keV transition to the ground state. This is consistent with the low E2 collectivity of even-even nuclei of ^{134}Sn and ^{136}Te. Such picture, however, seems to be in contradiction with our new (preliminary) results presented here.

The results presented at this Conference were recently obtained by the IS441 collaboration at the ISOLDE facility at CERN. We have used the Advanced Time-Delayed method (ATD) [4] to measure level lifetimes in nuclei populated in the beta decay of ^{134,135,136}Sn. Critical to the success of this experiment was a strong suppression of isobaric contaminants that made it impossible to detect gamma-rays in the decay of ^{136}Sn in previous attempts.

The two main criteria for the "quality" of radioactive ion beams are the beam intensity, *i.e.* the number of ions per second of the desired isotopes, and the beam purity, *i.e.* the presence or absence of admixtures of other radioactive (or stable) isotopes or isobars. The present experiment profited largely from an improvement of the beam purity compared to previously available beams. This improvement is discussed next.

2. Radioactive ion beam production

Previously relatively pure beams of neutron-rich tin isotopes at ISOLDE had been produced by selective ionization of tin with the resonance ionization laser ion source (RILIS) [5, 6]. However, to assure a sufficiently rapid release the RILIS ion source cavity must be kept hot. This will unfortunately cause significant surface ionization of those isobaric elements that have low ionization potentials [7]. The isobaric Sb to Xe isotopes are practically not surface ionized, but Cs (ionization potential 3.89 eV) and to slightly less extent also Ba (ionization potential 5.21 eV) are very efficiently surface ionized in the hot Ta or W cavity of the RILIS. For decay spectroscopy experiments such background is particularly problematic at masses 135 (^{135m}Cs and ^{135m}Ba), 136 (^{136g,m}Cs) and 137 (^{137m}Ba).

Another way to produce pure ISOL beams is the separation of an abundantly populated molecular sideband. The HRIBF group at Oak Ridge observed accidentally rather pure tin beams in the molecular sideband SnS^+ which was produced by a sulfur impurity in the target material [8]. The amount of possible SbS^+ and TeS^+ contaminants was not detectable. Detailed studies were performed at GSI-ISOL by Reinhard Kirchner on the dependence of the SnS^+/Sn^+ ratio and the suppression of isobaric contaminants by leaking in a well-controlled way vapors of sulfur into the ion source [9].

Natural sulfur contains 95% ^{32}S, but also 0.75% of ^{33}S, 4.2% of ^{34}S and 0.02% of ^{36}S. Thus for neutron-rich tin isotopes, an unwanted mixture of different molecular sidebands would occur at the same mass. Since the production cross-sections drop from ^{132}Sn towards the neutron-rich side by about one order of magnitude per additional neutron, the $^{136}Sn^{32}S^+$ beam would suffer from contaminations with $^{134}Sn^{34}S^+$ and $^{132}Sn^{36}S^+$ that are stronger than the wanted beam. To avoid these ambiguities we used sulfur isotopically enriched to $> 99.9\%$ ^{34}S. During the run the sulfur was continuously leaked into a standard ISOLDE UC_x/graphite target (20 cm length, 45 g/cm^2 ^{238}U) connected to a MK5 ("hot plasma") ion source [10].

Throughout the entire run the molecular $Sn^{34}S^+$ beams were of comparable magnitude to the respective Sn^+ beams, but by far purer. Isobaric contaminations in the sulfide sideband were generally negligible, except for barium sulfide.

More details about the production and yields of ISOL beams of tin isotopes can be found in the PhD thesises of Joinet [11] and Arndt [12] and in an upcoming paper [13].

3. Experiments and results

For the study of the decay of ^{136}Sn the mass separated beam of $A = 170$ was selected using the High Resolution Separator (HRS) at ISOLDE to deliver the molecular $^{136}Sn^{34}S^{+}$ beam into the experimental station. The beam was stopped on a thin Al foil in front of the beta fast timing detector. In total, the experimental setup included five detectors: three fast timing scintillators and two large volume 100% Ge detectors. The fast timing gamma scintillators included a cylindrical 2.5 by 2.5 cm $LaBr_3$(Ce) and our standard large fast timing BaF_2 crystal in the shape of a truncated cone. All scintillators were coupled to the fast response XP2020 URQ tubes. The present study represents only the third application of the $LaBr_3$(Ce) crystal to ultra fast timing measurements. The crystal provided by Saint Gobain had the energy resolution of about 3.5% at 661 keV, which is much superior to the resolution of 9.0% for our BaF_2 crystal used in the run. The time resolutions of both gamma-ray crystals were very similar yet BaF_2 scintillator had much higher efficiency, which is an important factor for measurements on exotic nuclei.

Although the data analysis is still in progress, yet based on our preliminary results it is certain that the new production techique has provided us with a wealth of interesting results on the exotic nuclei ^{134}Sb and ^{135}Sb. In particular, we were able to identify for the first time gamma transitions and levels in ^{135}Sb populated from the beta-delayed neutron emission of ^{136}Sn. These would be mainly low spin states, which are weakly populated in the decay of the $7/2^-$ ground state of ^{135}Sn. Our gamma–gamma coincidences collected in the two Ge detectors have revealed strong coincidences between the 282 keV line (which is the known transition connecting the first excited state and the ground state) and the 241 and 158 keV lines, see Fig. 1. The latter two were not in coincidence with one another. Since the second one was observed in the beta decay of ^{135}Sn while the former was not, therefore the 241 keV line de-exciting the state at 523 keV is our prime candidate for the previously unobserved $1/2^+$ state. This state is predicted [14] at 527 keV in excitation energy (note the very close energy match) and is expected to be mainly due to the coupling of the $d_{5/2}$ state to the collective core. Consequently the 241 keV transition should be E2 in character and one expects its E2 transition strength to be somewhat similar to that of the core, thus for ^{134}Sn. The expected half life of the 523 keV state should then be about a few nanoseconds.

Indeed, using the fast timing triple $\beta\gamma\gamma$(t) coincideces and the 241–282 keV gamma cascade we have measured the half-life for this 523 keV state as $T_{1/2}$=1.2(1) ns (preliminary result), see Fig 2. From this lifetime, we deduce a very collective B(E2; $1/2^+ \rightarrow 5/2^+$) value for this transition of

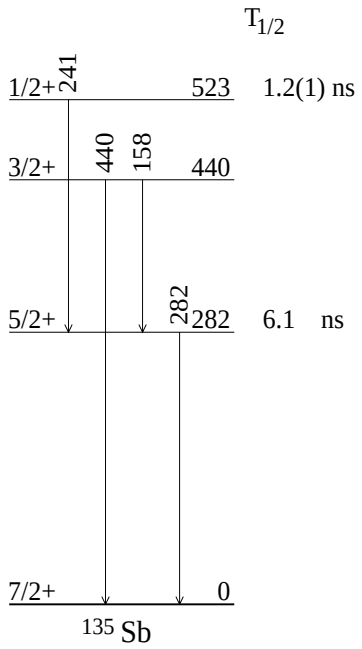

Fig. 1. Partial decay scheme for the beta delayed neutron emission of ^{136}Sn into ^{135}Sb, indicating the new excited state at 523 keV identified as $1/2^+$. Note its half-life of 1.2 ns has been also measured in this work.

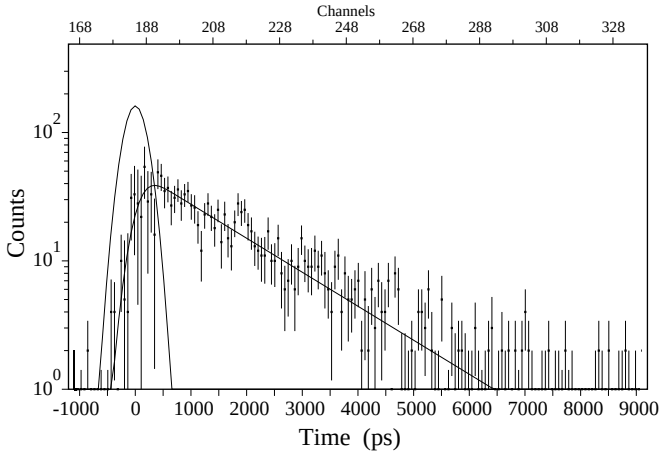

Fig. 2. The time delayed spectrum based on a partial data analysis from the run. The fitted half-life for the 523 keV state in ^{135}Sb is 1.2(1) ns (preliminary value).

13(1) W.u., which is much more collective than the B(E2) for the 2^+ to 0^+ transition in the core nucleus of ^{134}Sn, which is 1.4(2) W.u. Correcting for the spin factor (a change by a factor of 3), it still gives a B(E2; $5/2^+ \rightarrow 1/2^+$) value of 4.3 W.u., thus well above the limits expected from the excitation of the core. It remains to be seen whether the new results will be easily interpreted within the shell model calculations particularly if combined with the properties of other states in ^{135}Sb.

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